LiteBIRD

A Small Satellite for the Studies of B-mode Polarization and Inflation from Cosmic Background Radiation Detection

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On behalf of the LiteBIRD working group
LiteBIRD project overview

- **Scientific goal**
  - Stringent tests of cosmic inflation at the extremely early universe

- **Observations**
  - Full-sky CMB (i.e. mm wave) polarization survey at a degree scale

- **Strategy**
  - Roadmap includes ground-based projects as important steps
  - Focus on signals of inflationary gravitational waves imprinted in CMB polarization
  - Synergy with ground-based super-telescopes

- **Project status/plans**
  - Working group authorized by SCSS, supported by JAXA
  - Mission definition review in 2013, target launch year ~2020

CMB : Cosmic Microwave Background
LiteBIRD roadmap

- Ground-based projects as important steps
- Verification of key technologies
- Good scientific results
- International projects

POLARBEAR

POLARBEAR-2

GroundBIRD

LiteBIRD
58 members (as of Aug.15, 2012)

International and interdisciplinary

KEK
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K. Yotsumoto

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M. Dobbs

ARBL
J. Borrill

UT Austin
E. Komatsu

IPMU
N. Katayama

Yokohama NU.
S. Murayama
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K. Yotsumoto

Okayama U.
H. Ishino
A. Kibayashi
S. Mima
Y. Mibe

JAXA engineers and
Mission Design Support Group

X-ray astrophysicists
(JAXA)

Infrared astronomers
(JAXA)

CMB experimenters
(Berkeley, KEK, McGill,
Eiichiro)

Superconducting Device
(Berkeley, RIKEN, NAOJ,
Okayama, KEK etc.)

+ Korea U. under consideration
LiteBIRD mission

• Check representative inflationary models

  • requirement on the uncertainty on $r$

  (stat. $\oplus$ syst. $\oplus$ foreground $\oplus$ lensing) $\delta r < 0.001$

No lose theorem of LiteBIRD

- Many inflationary models predict $r > 0.01 \rightarrow > 10\sigma$ discovery
- Representative inflationary models (single-large-field slow-roll models) have a lower bound on $r$, $r > 0.002$, from Lyth relation.
  - no gravitational wave detection at LiteBIRD $\rightarrow$ exclude representative inflationary models (i.e. $r < 0.002$ @ 95% C.L.)
- Early indication from ground-based projects $\rightarrow$ power spectra at LiteBIRD!

Huge impact on cosmology in any case
LiteBIRD system overview

Bore sight

Spin axis

Superconducting Focal plane (100mK)

Primary mirror (4K)

HWP

2ndary mirror (4K)

Cryocoolers (ST/JT + ADR)

Solar panels

Standard bus system for JAXA’s small satellites
Three key technologies to make LiteBIRD light

- Small mirrors (~60cm)

- Warm launch with mechanical coolers
  - Technology alliance with SPICA for pre-cooling (ST/JT)
  - Alliance with DIOS (X-ray mission) for ADR

- Multi-chromatic focal plane
  - \( \sim 2000 \) TES (\( T_{\text{bath}} = 100 \text{mK}, \frac{\delta \nu}{\nu} \sim 0.3 \)), or equivalent MKIDs
  - Technology demonstration with ground-based projects (POLARBEAR, POLARBEAR-2, GroundBIRD)
## Major system requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirements</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>LEO (~500km) or L2</td>
<td>Launch vehicle: Epsilon or H2</td>
</tr>
<tr>
<td>Observing time</td>
<td>&gt; 2 years</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 450kg</td>
<td>from Epsilon payload requirement</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 500W</td>
<td>from JAXA’s standard bus system</td>
</tr>
<tr>
<td>Total sensitivity</td>
<td>&lt; 3µKarcmin</td>
<td>2µKarcmin as the design goal</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>&lt; 30arcmin for 150GHz</td>
<td>descoping requires justification</td>
</tr>
<tr>
<td>Observing frequencies</td>
<td>50-270 GHz (or wider)</td>
<td>≥ 4 bands</td>
</tr>
<tr>
<td>Modulation/Demodulation</td>
<td>HWP rotation &gt; 1Hz</td>
<td>HWP = Half Wave Plate</td>
</tr>
<tr>
<td>$1/f$ knee ($f$) × scan rate ($R$)</td>
<td>$R/f &gt; 0.06$ rpm/mHz (e.g. $R &gt; 1.2$ rpm for $f = 20$ mHz)</td>
<td>spec. for the case HWP stops</td>
</tr>
<tr>
<td>Telemetry</td>
<td>&gt; 10GB/day</td>
<td>w/ Planck-type data suppression</td>
</tr>
<tr>
<td>Total systematic errors</td>
<td>&lt; 18nK² on C^{BB} (l=2)</td>
<td></td>
</tr>
</tbody>
</table>

These requirements are still subject to modifications in the feasibility studies.
LiteBIRD scan strategy: LEO case

- Spin axis rotation about anti-sun axis (i.e. satellite period around the earth) $f_s = 90$ min
- Boresight axis rotation about spin axis $f_b \sim 0.6$ rpm

Uniformity and cross link nearly as good as those at L2
LiteBIRD optics

- **HWP example**: HWP example from T. Matsumura, doctoral thesis.
- **4K Reflective Optics**: Boresight with Crossed Mizuguchi-Dragone
- **Prototype mirrors**: Mirror diameter ~60cm for ~0.5° angular resolution (@150GHz) is sufficient for both reionization and recombination bumps.

Focal plane requirement

Noise level: goal = $2 \mu K \cdot \text{arcmin}$
(requirement: $< 3 \mu K \cdot \text{arcmin}$)

To be well below “lensing floor”
Foreground removal and observing bands

• Foreground removal

\[ \geq 4 \text{ bands in 50-270GHz} \]

N. Katayama and E. Komatsu,
(arXiv:1101.5210)

pixel-based polarized foreground removal
(model-independent)
very small bias
\[ r \sim 0.0006 \]
with 60, 100, 240GHz (3 bands)
LiteBIRD band selection for multi-chroic pixels

We chose the band locations with the following reasons.

1. Katayama-Komatsu (2010) suggested the range of frequency from 50-270 GHz based on the template subtraction.
2. We want to exclude the CO lines.
3. From the practical consideration such as AR coating on a lenslet array, it is reasonable to limit the bandwidth to \( \Delta v/v \sim 1 \).

Above three constraints naturally put us to the band locations.
LiteBIRD focal plane design

UC Berkeley TES option

2022 TES bolometers

\( T_{\text{bath}} = 100 \text{mK} \)

tri-chroic (60/78/100GHz)

1.8\( \mu \text{Karcmin} \) (w/ 2 effective years)

Strehl ratio > 0.8

8 cm site-to-site wafer cut
LiteBIRD focal plane design

UC Berkeley TES option

2022 TES bolometers

\[ T_{\text{bath}} = 100 \text{mK} \]

tri-chroic (60/78/100GHz)

Band centers can be distributed to increase the effective number of bands

More space to place <60GHz detectors

POLARBEAR focal plane as a prototype

Strehl ratio > 0.8
Replace analog feedback loop with Digital Active Nulling (DAN) to achieve 64 MUX led by McGill University (supported by CSA)

Frequency-domain multiplexing

Frequency-domain multiplexing (MUX) used in POLARBEAR, SPT, EBEX etc. (8-16 MUX)

toward LiteBIRD

Berkeley-KEK-McGill-NIST
MKID option for higher MUX factor

300 mK stage

102 pixel MKID

NAOJ

RIKEN

KEK

OKAYAMA

LiteBIRD is currently the guiding force for the MKID development in Japan

Si lens-array

Double slot antenna + Al MKID

Electrical noise measurement
M. Naruse et al. 2012
Expected sensitivity on $r$

- **Foreground limited**
- **Lensing limited**
- **Cosmic variance limited**

Katayama-Komatsu with 2 effective years
Both cases satisfy the requirement on statistical error
Advantages of LiteBIRD

• Not a pathfinder; small but no compromise in r sensitivity
• More launch options than a big satellite
• Less expensive
  – With LiteBIRD plus ground-based super-telescopes (e.g. O(100K) bolometers w/ arcminute angular resolution) as one package, science reach nearly as good as a large CMB polarization mission with ~1/5 total cost
• Better in terms of cooling (mirrors and baffles)
• The whole spacecraft can be tested in a large cryogenic test chamber
  – Better calibration data \(\rightarrow\) less systematic uncertainties
  – Better pre-flight investigations \(\rightarrow\) less chance of failure
Funding

• “Cosmic Background Radiation” selected as one of “innovative areas for research” by MEXT (PI: M. Hazumi)
  – JFY2009 – JFY2013: 14.3M$
  – QUIET, POLARBEAR, LiteBIRD, CIBER etc.

• Joint budget request (KEK, NINS) in consideration
  – ~100M$ needed (+ launch cost)

• International collaboration should be pursued actively.
  – Detector development matching fund from NASA will help a lot
  – Launch not limited to Epsilon or H2 depending funding progress
Support from research communities

- Japanese High Energy Physics (HEP) community has identified CMB polarization measurements and dark energy survey as two important areas of their “cosmic frontier”.

- Japanese radio astronomy community also expressed their support to LiteBIRD.

- Cosmology community (theory) is also supporting LiteBIRD and contributing to the science case.

- SCSS added “fundamental physics” as a target for space programs in next 20 years
Conclusion

• CMB polarization will be the frontier in post-Planck era
  – Best probe to discover primordial gravitational waves
  – Unique tests of inflation and quantum gravity

• The goal of LiteBIRD is to search for primordial gravitational waves with the sensitivity of $\delta r < 0.001$, for testing all the representative inflationary models.

• The strategy of LiteBIRD is to focus on $r$ measurements. The powerful duo (LiteBIRD and ground-based super-telescopes) will be the most cost-effective way.

• No show-stopper in design studies so far. Technology verification in ground-based projects in next ~3 years will be crucial. The LiteBIRD roadmap includes such ground-based projects.
Contacts

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  – US-PI: Adrian T. Lee (UC Berkeley)
  – JAXA contact: Kazuhisa Mitsuda (ISAS/JAXA)

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  – Director: Tadayuki Takahashi (ISAS/JAXA)

• Steering Committee for Space Science (SCSS)
  – Chair: Saku Tsuneta (ATC/NAOJ)